The Volume-Outcome Effect for Abdominal Aortic Surgery

Differences in Case-Mix or Complications?

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Hypothesis: Variation in postoperative complications after abdominal aortic surgery contributes to differences in mortality between high- and low-volume hospitals.

Background: Hospitals with high surgical volume have been shown to have lower operative mortality rates for complex vascular surgery than those with low volumes. Differences in the rates of complications among hospitals may explain this variation in mortality.

Methods: Adult patients who underwent abdominal aortic surgery in Maryland from 1994 to 1996 (N=2987) were included. The primary dependent variable was in-hospital mortality and the independent variables included hospital surgical volume, patient case-mix variables, and several specific postoperative complications. Two sequential analyses using multiple logistic regression were performed to determine the relative importance of independent variables in predicting mortality.

Results: Hospitals with high surgical volume had a lower mortality rate (5.6%) than those with medium (6.8%) and low (8.7%) volumes (P=.03). In the first multivariate analysis, after adjusting for patient case-mix, having surgery at a high-volume hospital remained associated with a 37% reduction in mortality (odds ratio [OR], 0.63; 95% confidence interval [CI], 0.42-0.92; P=.02). Patients at high-volume hospitals had a decreased relative risk (RR) of several complications: pulmonary failure (RR, 0.45; 95% CI, 0.36-0.55), reintubation (RR, 0.53; 95% CI, 0.44-0.64), pneumonia (RR, 0.74; 95% CI, 0.55-0.99), cardiac complications (RR, 0.63; 95% CI, 0.51-0.78), and shock (RR 0.27; 95% CI, 0.10-0.75). In the second multivariate analysis, which included complications, hospital volume was no longer a significant predictor of mortality. However, several postoperative complications remained significant predictors of mortality.

Conclusions: The effect of hospital volume on mortality after abdominal aortic surgery is attributable to differences in postoperative complications and not preoperative differences in case-mix. Efforts to reduce the rates of postoperative complications may reduce mortality rates at low-volume hospitals.

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Hospitals that perform high volumes (HVHs) of complex vascular surgery have superior outcomes to those that perform low volumes (LVHs). Two recent population-based studies estimated that regionalization of high-risk surgery, including some complex vascular procedures, could potentially save thousands of lives each year in the United States. The relationship between hospital surgical volume and outcome is likely a complex interaction involving differences in preoperative patient selection, technological resources, surgeon and anesthesiologist experience, postoperative management, and other processes of care. By identifying the factors that explain the volume-outcome relationship, we can focus quality improvement efforts on these factors and reduce mortality at LVHs without disrupting access to care.

Variation in postoperative complications may be a factor that explains the volume-outcome relationship. There is tremendous variation among hospitals in the rates of postoperative complications after complex surgical procedures. Postoperative complications are a marker for poor quality and are associated with clinical and economic outcomes after high-risk surgical procedures. However, as an alternative explanation for poor outcomes at LVHs, there may be significant differences in patient characteristics between LVHs and HVHs. The objectives of this study were to determine whether the effect of hospital surgical volume on in-hospital mortality after abdominal aortic surgery is dependent on differences in preoperative patient characteristics or postoperative complications. We
PATIENTS AND METHODS

PATIENTS

Data on all patients discharged from one of the 52 acute-care hospitals in Maryland with a primary procedure code for abdominal aortic surgery from January 1994 to December 1996 were included. Data were obtained from the non-confidential version of the Uniform Discharge Dataset maintained by the Health Services Cost Review Commission (HSCRC) of Maryland. The primary procedure codes were the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) \(^{13}\) codes for resection of abdominal aorta with replacement (ICD-9-CM code 3844) and aorto-iliac-femoral bypass (ICD-9-CM code 3925). Nine patients younger than 30 years who had injury to a blood vessel (ICD-9-CM code 902) were excluded. Demographic information (age, sex, race), nature of admission, vital status at discharge, length of stay, hospital charges, operating physician, hospital identification number, and up to 14 secondary diagnostic and procedure ICD-9-CM codes were obtained from the hospital discharge abstracts.

MORTALITY AND CASE-MIX VARIABLES

The primary outcome variable was in-hospital mortality. Two sequential analyses were performed to assess the relative importance of patient characteristics and postoperative complications. The first of the analyses included a multivariate case-mix adjustment to determine if differences in in-hospital mortality between HVHs and LVHs were attributable to differences in measurable patient characteristics. To account for differences in case-mix between hospitals, we adjusted for patient demographics (age, sex, and race), comorbid disease, and severity of illness. The Romano modification of the Charlson comorbidity index for the use of ICD-9-CM codes from the index hospitalization was used to determine the importance of 10 comorbid diseases in predicting in-hospital mortality. \(^{16,17}\) For the severity of disease adjustment, the nature of admission (elective, urgent, and emergent), the extent of the procedure (aortic aneurysm repair vs aorto-iliac bypass), and ruptured vs nonruptured aortic aneurysms (ICD-9-CM code 4413) were entered into the multivariate model. Patients undergoing aortoiliac bypass were not further classified as having occlusive vs aneurysmal disease, except for those who were in the group that had ruptured aneurysms.

Also wanted to identify specific aspects of care that explain the volume-outcome relationship to aid in quality improvement efforts at LVHs and to optimize patient outcomes.

RESULTS

PATIENT DEMOGRAPHICS

Among the 2987 patients, 1840 (62%) had abdominal aortic aneurysm (AAA) repair and 1147 (38%) had an aortobifemoral bypass. The overall crude in-hospital mortality rate was 7.0%. High-volume hospitals had a lower mortality rate (5.6%) than MVHs (6.8%) and LVHs (8.7%) \((P = .03)\), with an incremental increase in mortality with decreasing volume. When hospital surgical volume was examined as a dichotomous variable (>36 or <36 procedures per year), HVH was still associated with decreased mortality compared with LVH (5.6% vs 8.0%; \(P = .005)\). Because mortality rates were similar at MVHs and LVHs, they were combined and compared with HVHs for the remaining analyses. Patients at HVHs were more

POSTOPERATIVE COMPLICATIONS

The second stage of analysis involved entering the postoperative complications into the model to investigate their contribution to the differences in mortality between HVHs and LVHs. The postoperative complications were taken from the secondary ICD-9-CM codes available in the HSCRC database. The complications were previously validated and include the following: aspiration (ICD-9-CM codes 507 and 9973), pulmonary insufficiency (ICD-9-CM codes 5184, 5185, and 5188), pneumonia (ICD-9-CM codes 480–487), reintubation (ICD-9-CM code 9604), sepsisemia (ICD-9-CM code 038), postoperative infection (ICD-9-CM code 9985), cardiac complications (ICD-9-CM code 9971), cardiac arrest (ICD-9-CM code 4257), acute myocardial infarction (ICD-9-CM code 410), acute renal failure (ICD-9-CM code 584), reoperation for bleeding (ICD-9-CM codes 3941, 3949, and 3998), and surgical complications after a procedure (ICD-9-CM codes 9981, 9982, 9983). To validate preoperative comorbid disease and postoperative complication ICD-9-CM codes, 25 medical records were reviewed and compared with the HSCRC diagnoses. The 2 sources demonstrated 96% agreement.\(^{10}\)

STATISTICAL ANALYSIS

Three hospital surgical volume categories (LVH, medium-volume hospital [MVH], and HVH) were established based on tertiles to divide the patients into 3 equally sized groups. The volume cutoff points were established beforehand to reduce bias. Using this method, hospitals were designated as LVH (<20 procedures per year), MVH (20–36 procedures per year), or HVH (>36 procedures per year). These volume cutoffs are consistent with those used for previous volume-outcome studies.\(^{1,6}\) Low-volume hospitals and MVHs were combined and compared with HVHs for some analyses. Descriptive analysis of baseline characteristics and crude in-hospital mortality rates for patients at HVHs and LVHs were performed. Univariate tests of association used the \(\chi^2\)-test and the Wilcoxon rank-sum test, and simple logistic regression and simple linear regression were applied where appropriate. Two sequential analyses using multiple logistic regression of in-hospital mortality were performed. Diseases in the comorbidity index were treated as individual dichotomous variables (presence vs absence of disease). Patient characteristics with a significant univariate association with mortality \((P < .1)\) were included in the first-stage multivariate analysis. Complications significantly associated with mortality \((P < .1)\) were included in the second-stage multivariate analysis. Statistical significance was set at \(P < .05\). All statistical analyses were performed using STATA 6.0 (Stata Corp, College Station, Tex).
likely to be nonwhite (13% vs 7%; P < .05) but were similar to patients at LVHs with respect to other demographic characteristics and comorbid disease (Table 1). Fewer patients at HVHs underwent AAA repair (58% vs 65%; P < .05) but there were more ruptured AAA repairs at HVHs (9.4% vs 7.4%; P < .05) (Table 1).

### CASE-MIX ADJUSTMENT

In the univariate analysis, several case-mix variables were associated with in-hospital mortality. The type of procedure performed was associated with a significant difference in mortality, with patients who underwent AAR repair having a mortality of 9.1% compared with 3.6% for patients who underwent aortofemoral bypass. This finding is largely due to the high mortality associated with repair of ruptured AAAs (39.2%). The in-hospital mortality associated with repair of intact AAA repair was much lower at 4.7%, which is not significantly different from an aortofemoral bypass (P = .08). The nature of admission was also a significant predictor of in-hospital mortality, with increasing mortality risk associated with increasing urgency (elective = 2.9%, urgent = 7.0%, and emergent = 19.4%; P < .001). Age older than 65 years was associated with an in-hospital mortality of 9.0% compared with 2.4% for those younger than 65 years (P < .001). Other univariate risk factors for in-hospital mortality included chronic renal disease (P < .001), mild liver disease (P = .002), and a history of myocardial infarction (P = .08).

In the first-stage multivariate analysis, after adjusting for patient case-mix, having surgery at an HVH remained associated with a 37% reduction in mortality (odds ratio [OR], 0.63; 95% confidence interval [CI], 0.42-0.92; P = .02). Several case-mix variables were also independently associated with mortality but these did not account for the differences between HVHs and LVHs. The significant case-mix variables include age (OR, 1.1; 95% CI, 1.06-1.1; P < .001), urgent admission (OR, 2.4; 95% CI, 1.5-4.1; P = .001), emergent admission (OR, 2.8; 95% CI, 1.8-4.4; P = .001), ruptured aneurysm (OR, 5.4; 95% CI, 3.4-8.6; P < .001), diabetes (OR, 4.9; 95% CI, 1.4-17.5; P = .01), and chronic renal disease (OR, 7.4; 95% CI, 4.5-12.2; P < .001) (Table 2).

### POSTOPERATIVE COMPLICATIONS

In a univariate analysis, HVHs had a decreased relative risk (RR) of several postoperative complications compared with LVHs (Figure and Table 3). Complications less likely to occur at an HVH included the following: pulmonary failure (RR, 0.45; 95% CI, 0.36-0.55), reintubation (RR, 0.53; 95% CI, 0.44-0.64), pneumonia (RR, 0.74; 95% CI, 0.55-0.99), cardiac complications (RR, 0.63; 95% CI, 0.51-0.78), and shock (RR 0.27; 95% CI, 0.10-0.75). In the second-stage multivariate analysis, with postoperative complications entered into the model, hospital volume was no longer a significant predictor of mortality. Several complications were independent predic-

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Table 1. Demographic Characteristics and Comorbid Diseases for Patients Undergoing Abdominal Aortic Surgery at High- and Low-Volume Hospitals in Maryland*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>High-Volume Hospitals</th>
<th>Low-Volume Hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of patients</td>
<td>1397 (47)</td>
<td>1590 (53)</td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>68 (10)</td>
<td>68 (10)</td>
</tr>
<tr>
<td>Male sex</td>
<td>936 (67)</td>
<td>1094 (69)</td>
</tr>
<tr>
<td>Race†</td>
<td>1206 (87)</td>
<td>1462 (92)</td>
</tr>
<tr>
<td>Ruptured aneurysm†</td>
<td>812 (58)</td>
<td>1028 (65)</td>
</tr>
<tr>
<td>Emergent admission</td>
<td>284 (20)</td>
<td>361 (22)</td>
</tr>
<tr>
<td>Urgent admission</td>
<td>182 (13)</td>
<td>161 (10)</td>
</tr>
<tr>
<td>Race†</td>
<td>149 (11)</td>
<td>211 (13)</td>
</tr>
<tr>
<td>Male sex</td>
<td>1206 (87)</td>
<td>1462 (92)</td>
</tr>
<tr>
<td>Male sex</td>
<td>68 (10)</td>
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</tr>
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<td>1397 (47)</td>
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</tr>
</tbody>
</table>

*Data are given as number (percentage) of patients unless otherwise indicated. COPD indicates chronic obstructive pulmonary disease.
†More than 36 procedures per year.

Table 2. Hospital and Patient Characteristics That Independently Predict In-Hospital Mortality From a Multiple Logistic Regression Model of Abdominal Aortic Surgery in Maryland*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Risk of In-Hospital Mortality</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High volume†</td>
<td>0.63 (0.42-0.92)</td>
<td>.02</td>
</tr>
<tr>
<td>Age</td>
<td>1.1 (1.06-1.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Urgent admission</td>
<td>2.4 (1.5-4.1)</td>
<td>.001</td>
</tr>
<tr>
<td>Emergent admission</td>
<td>2.8 (1.8-4.4)</td>
<td>.001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>4.9 (1.4-17.5)</td>
<td>.01</td>
</tr>
<tr>
<td>Ruptured aneurysm†</td>
<td>5.4 (3.4-8.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Chronic renal disease</td>
<td>7.4 (4.5-12.2)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Data are given as odds ratio (95% confidence interval) unless otherwise indicated.
†More than 36 procedures per year.

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tors of mortality: pulmonary failure (OR, 1.5; 95% CI, 1.0-2.4; \( P = .05 \)), acute myocardial infarction (OR, 4.2; 95% CI, 2.0-8.4; \( P < .001 \)), shock (OR, 3.9; 95% CI, 1.3-11.5; \( P = .01 \)), acute renal failure (OR, 8.9; 95% CI, 5.7-14.1; \( P < .001 \)), sepsis (OR, 7.8; 95% CI, 4.5 to 13.6; \( P < .001 \)), surgical complications (OR, 2.7; 95% CI, 1.7-4.2; \( P < .001 \)), and reintubation (OR, 2.9; 95% CI, 1.9-4.4; \( P < .001 \)).

**Table 3. Univariate Relative Risk of Several Postoperative Complications at High- and Low-Volume Hospitals After Abdominal Aortic Surgery in Maryland, 1994-1996* **

<table>
<thead>
<tr>
<th>Complication</th>
<th>High Volume, %</th>
<th>Low Volume, %</th>
<th>( P ) Value</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shock</td>
<td>0.3</td>
<td>1.2</td>
<td>.007</td>
<td>0.27 (0.10-0.75)</td>
</tr>
<tr>
<td>Pulmonary failure</td>
<td>7.5</td>
<td>16.7</td>
<td>&lt;.001</td>
<td>0.45 (0.36-0.55)</td>
</tr>
<tr>
<td>Reintubation</td>
<td>9.9</td>
<td>18.7</td>
<td>&lt;.001</td>
<td>0.53 (0.44-0.64)</td>
</tr>
<tr>
<td>Cardiac complications</td>
<td>8.2</td>
<td>13.0</td>
<td>&lt;.001</td>
<td>0.63 (0.51-0.78)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>4.6</td>
<td>6.2</td>
<td>&lt;.05</td>
<td>0.74 (0.55-0.99)</td>
</tr>
</tbody>
</table>

*RR indicates relative risk; CI, confidence interval.

Patients undergoing abdominal aortic surgery in Maryland have a lower rate of in-hospital mortality at HVHs compared with those at LVHs during the same period. The volume-outcome effect observed in this study is consistent with previous work demonstrating improved outcomes for several high-risk surgical procedures associated with increasing hospital volume.\(^1\)\(^-\)\(^6\) However, our study demonstrates that the volume-outcome effect may, in part, be due to differences in the rates of several postoperative complications. Patients at LVHs were at an increased risk of pulmonary failure, pneumonia, reintubation, cardiac complications, and shock.

It is also important to note the interaction between hospital volume and postoperative complications. When the complications were entered into the multivariate model for in-hospital mortality, hospital volume was no longer a significant predictor of mortality. High-volume hospitals should therefore target postoperative complications for systematic quality improvement efforts to decrease in-hospital mortality rates and improve patient outcomes. Low-volume hospitals should track the incidence and determine risk factors for pulmonary and cardiac complications and then systematically examine their care of patients undergoing abdominal aortic surgery for areas in which they can improve quality. Some evidence has shown that having intensive care units with optimal physician and nurse staffing decreases mortality, complications, and resource use after complex surgical procedures.\(^10\)\(^-\)\(^18\) If LVHs were able to decrease postoperative complication rates, their outcomes may improve and ultimately approach those at HVHs.

Two decades have passed since Luft et al\(^18\) demonstrated an association between hospital volume and outcomes after specific complex surgical procedures. Since then, many studies using state administrative databases, the national Medicare database, and nationally representative databases have demonstrated improved outcomes for HVHs compared with LVHs for a variety of high-risk surgical procedures.\(^1\)\(^-\)\(^7\) The association between hospital volume and improved outcomes after abdominal aortic surgery is well established. In a recent study using hospital discharge data from Maryland, Dardik et al\(^19\) showed that both high surgeon and hospital volume were associated with a decreased risk of in-hospital mortality for both ruptured and intact AAA repair. In another recent study based on discharge data from Florida hospitals, surgeon volume, hospital volume, and subspecialty board certification in vascular surgery were associated with outcomes after AAA repair and carotid endarterectomy.\(^7\)

Despite the known advantage of undergoing surgery at HVHs, little has been done to systematically refer patients to recognized centers of excellence. The resistance to concentrate surgery in HVHs is a complex health policy issue. For example, selective referral may negatively affect access to care in rural areas and the practices of rural surgeons who depend on surgical volume to maintain technical skills and generate revenue. However, recent data show that many patients are undergoing elective surgery at LVHs in urban areas.\(^9\) Selective regionalization of patients in urban areas alone could therefore result in a significant reduction in unnecessary deaths. Some evidence indicates that patients may prefer to have surgery locally and would accept increased risks in mortality to avoid traveling to distant HVHs for surgery.\(^20\) However, this evidence is based on the population undergoing elective surgery at one Veterans Administration Hospital in a rural area and may not be generalizable to other patient populations. Furthermore, even if patients prefer to seek care at a remote center, elderly patients may have decreased mobility or insufficient financial resources to travel to centers of excellence—although targeting patients in an urban center would obviate the need for increased travel.

Recently, the Business Roundtable’s Leapfrog group has proposed 3 “leaps” in patient safety.\(^21\) Among these, selective referral to hospitals with high volumes of several surgical procedures was proposed. Abdominal aortic aneurysm repair was one of the procedures chosen for regionalization. Birkmeyer et al\(^22\) calculated the number of lives that could be saved by “universal adoption” of these patient safety initiatives. It was estimated that approximately 2600 lives could be saved in the United States each year by selective hospital referral alone. The implications of these minimum volume standards on referral patterns and viability of LVHs have yet to be determined.

There are several limitations to our study. First, our population only represents a single state and may not have
external validity to other states with different hospital profiles. Furthermore, differences in outcomes between hospitals may be due to differences in unmeasured patient case-mix variables that we were unable to include in the multivariate analysis. An attempt was made to adjust for case-mix using patient demographics, comorbid disease, nature of admission, and ruptured vs unruptured aneurysm status (for patients undergoing AAA repair). In addition, the use of a prospectively acquired physiologic risk adjustment system (eg, APACHE III) would allow for more robust physiologic risk adjustment (especially for patients with ruptured AAA) but is not available in the HSCRC database. Furthermore, comorbid disease may be inadequately or incorrectly coded in the database and a prospective clinical database or patient medical record review would be more accurate.

This statewide observational study demonstrates that the beneficial effect of hospital volume on in-hospital mortality after abdominal aortic surgery is attributable to differences in postoperative complications and not preoperative differences in case-mix. While these findings support the regionalization of patients to HVHs of excellence for abdominal aortic surgery, LVHs could reduce in-hospital mortality by targeting postoperative complications for systematic quality improvement. If LVHs focus on decreasing the incidence of pulmonary and cardiac complications after abdominal aortic surgery, outcomes at these centers may improve and approach those at HVHs.


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REFERENCES